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Children's Exposure to Magnetic Fields Produced by U.S. Television Sets Used for Viewing Programs and Playing Video Games

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Two epidemiologic studies have reported increased risk of childhood leukemia associated with the length of time children watched television (TV) programs or played video games connected to TV sets. To evaluate magnetic field exposures resulting from these activities, the static, ELF, and VLF magnetic fields produced by 72 TV sets used by children to watch TV programs and 34 TV sets used to play video games were characterized in a field study conducted in Washington DC and its Maryland suburbs. The resulting TV-specific magnetic field data were combined with information collected through questionnaires to estimate the magnetic field exposure levels associated with TV watching and video game playing. The geometric means of the ELF and VLF exposure levels so calculated were 0.0091 and 0.0016 μT, respectively, for children watching TV programs and 0.023 and 0.0038 μT, respectively, for children playing video games. Geometric means of ambient ELF and VLF levels with TV sets turned off were 0.10 and 0.0027 μT, respectively. Summed over the ELF frequency range (6–3066 Hz), the exposure levels were small compared to ambient levels. However, in restricted ELF frequency ranges (120 Hz and 606–3066 Hz) and in the VLF band, TV exposure levels were comparable to or larger than normal ambient levels. Even so, the strengths of the 120 Hz or 606–3066 Hz components of TV fields were small relative to the overall ambient levels. Consequently, our results provide little support for a linkage between childhood leukemia and exposure to the ELF magnetic fields produced by TV sets. Our results do suggest that any future research on possible health effects of magnetic fields from television sets might focus on the VLF electric and magnetic fields produced by TV sets because of their enhanced ability relative to ELF fields to induce electric currents. Bioelectromagnetics 21:214–227, 2000.

Key words: ELF; VLF; appliances; residential; exposure assessment

INTRODUCTION

Two epidemiologic studies have reported associations between childhood leukemia risk and mothers' reports of their children's television (TV) viewing [London et al., 1991; Hatch et al., 1998] and use of TV sets for playing video games [Hatch et al., 1998]. One interpretation of these results is that exposure to the magnetic fields produced by TV sets and/or the hardware (i.e., video game controllers, joy sticks, power transformers) used to play video games is related to leukemia risk. However, neither epidemiologic study obtained any direct measure of magnetic or electric field exposure associated with the use of these appliances, so their exposure assessment was based solely on questionnaire data.

There appear to be no published systematic studies of the electric fields produced by television sets and there are only two published studies of the magnetic fields produced by these sources [Gauger, 1985; Preece et al., 1997]. Of the latter two, the first study [Gauger, 1985] evaluated five television sets located in homes. Gauger's measurement protocol focused on identifying and measuring the strongest magnetic fields produced by the various appliances he studied. Consequently, the magnetic fields he measured were usually near the sides or rear of TV sets rather than in front of the screen where a viewer would normally sit. Even so, he found that magnetic fields 1 m from TV sets were less than about 0.2 μT.

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Preece et al. [1997] measured the magnetic fields produced by 73 television sets in homes located in and near Bristol, England. These authors made an approximate separation of the magnetic fields produced by the television sets under study from fields produced by other sources. They reported the means ± standard deviations of the magnetic fields at distances of 50 and 100 cm in front of TV sets to be 0.26 ± 0.11 μT and 0.07 ± 0.04 μT, respectively. Since the television sets included in this study were manufactured for the European market, it is unclear how these data apply to US television sets.

Compared to TV sets, video display terminals (VDTs) used with computers have been studied in more depth [Harvey, 1982, 1983a,b, 1984; Stuchly et al., 1983; Marha and Charron, 1985; Guy, 1987; Jokela et al., 1989; Tofani and D'Amore, 1991; Sandström et al., 1993]. Some of these data will be discussed later in this paper.

The purpose of the current study was to characterize (1) the magnetic fields produced by a sample of TV sets actually used by children to view programs, (2) the magnetic fields produced by a sample of TV sets and related equipment that children used for playing video games, and (3) children's exposures to these fields. The goal was to evaluate whether observed epidemiologic associations between childhood leukemia and time spent watching TV programs or playing video games connected to TVs were potentially related to magnetic field exposures. A key goal was the acquisition of data to enable a more precise separation than has hitherto been possible of the magnetic fields produced by television sets from those produced by other residential sources. We did not measure electric fields because (1) there are few data suggesting that electric field exposure affects cancer incidence or progression in humans or animals [Portier and Wolfe, 1998], (2) ELF electric fields produced by TV sets are likely comparable to or smaller than normal residential ambient levels at locations where children sit while watching them [Sandström et al., 1993], and (3) because of the difficulty of and lack of standardization for making electric field measurements that properly take into account the perturbing effect of the bodies of subjects [Kaune and Gillis, 1981; Deno and Silva, 1984; Chartier et al., 1985].

MATERIALS AND METHODS

Subjects and Appliances

The sample consisted of the homes and children of volunteers who were either employed by Westat, Inc., or the National Cancer Institute or who learned about the study from employees of these two organizations. In all, 78 volunteer families with children aged 3–14 years were enrolled in the study during the summer of 1997. Volunteers were selected without any reference to the types or numbers of TV sets or video games they or their children used.

During an initial telephone interview of the 78 volunteers, TV sets and video games in each home were inventoried. Next, the oldest TV set was identified that was watched at least 2 h/week on average during the past 12 months by at least one of the children in the home. The oldest TV was selected for magnetic field measurements because the epidemiological studies that found associations between children's use of TV sets and leukemia [London et al., 1991; Hatch et al., 1998] were conducted during the 1980's and early 1990's. Similarly, in families with children who played video games, the oldest game system was selected. Magnetic field measurements were made while children used their video game system to play their most commonly used game.

Questionnaire

A brief questionnaire was administered to each volunteer mother by a trained interviewer. First, the names and ages were determined for each of the children who watched the eligible TV or played the eligible video game. Then, for each child, the following information was collected: The mother's estimate of the average daily time the child used the TV set during the previous 12 months; the location of child, as demonstrated by the child, while watching TV or playing video games; the mother's agreement or disagreement with the child about this location and, if there was disagreement, the location where the mother reported the child most often sat while watching TV or playing video games. The field technician then measured the distance between the TV and the location of the child. If mother and child agreed on this location, only one distance measurement was made; otherwise, two measurements were made.

Magnetic Characteristics of Television Sets

The primary source of the magnetic fields produced in front of a TV set is the internal system used to deflect the electron beam that forms the image on the face of the picture tube of the unit. (A detailed description of the operation of VDTs and TV sets is given by Kavet and Tell [1991].) Beam deflection is accomplished with two magnetic fields, one oriented in the vertical direction to produce horizontal deflection of the electron beam, the other oriented in the horizontal plane perpendicular to the axis of the picture tube to produce vertical deflection. The temporal waveforms of these two fields are those described as sawtooth waveforms (i.e., a linear rise in time, starting from some initial value, followed by a nearly instantaneous return to the starting point). It requires approximately 63.5 μs for the vertical field to complete one cycle, corresponding to a horizontal deflection frequency of 15.75 kHz. The vertical deflection frequency is 60 Hz. Since 60 Hz (and its first 50 harmonics) fall in the ELF frequency range (3–3000 Hz [IEEE, 1993]), it is convenient to refer to the vertical deflection field as the ELF field produced by TV sets. Similarly, since the horizontal deflection field is characterized by a base frequency of 15.75 kHz, it will be designated the VLF field, even though the harmonics of 15.75 kHz really lie in the LF band (30–300 kHz).

At any instant, the ELF or VLF field produced by either the horizontal or vertical deflection circuitry can be described by the values of its three vector components. All three components will exhibit a sawtooth waveform. The overall magnitude of a sawtooth magnetic field waveform can be summarized by the root-mean-square (rms) *total* field strength, also known as the broadband field strength. This waveform can also be decomposed into fundamental and harmonic components by using the methods of Fourier analysis [Mathews and Walker, 1965; CRC, 1978]. The rms magnitudes of the broadband and harmonic amplitudes are related. For example, for the ELF x component, $X_{ELF} = (n\pi/\sqrt{6})X_n$, where X_{ELF} is the broadband magnitude and X_n is the rms magnitude of the n^{th} harmonic. (Similar equations apply to the y and z components.) We define the resultant broadband magnitude, T_{ELF}, of the ELF field by the equation $T_{ELF} = \sqrt{X_{ELF}^2 + Y_{ELF}^2 + Z_{ELF}^2}$ and define the resultant value, T_n, of the n^{th} harmonic in a similar way. Then, it is easy to show that

$$T_{ELF} = \frac{n\pi}{\sqrt{6}} T_n. \quad (1)$$

Video Games

The typical video game evaluated in our study consisted of a central electronics module connected to the TV set, one or more game controllers (joy sticks), and a power transformer plugged directly into a wall outlet. The most common location for a game module was on the floor in front of the TV, but a substantial number were also placed on TV sets. Power transformers were normally located at wall plugs close to TVs and were, therefore, relatively remote from children playing games. The electronics module, joy sticks, and power transformer will collectively be referred to as video game hardware. Game software, in the form of plug-in game cartridges, is also required. All of our video game measurements were taken while subjects were playing their favorite game cartridges.

Magnetic Field Measurements

We used two different instruments to measure the ELF and the VLF magnetic fields produced by TV sets. Magnetic field waveforms with frequencies ranging from 0 through 3066 Hz were characterized using a Multiwave II Waveform Capture System (Electric Research and Management, State College, PA). We programmed this instrument to measure and retain for later analysis the instantaneous strengths of each of the three vector components (i.e., the x, y, and z components) of magnetic field strength at a nominal sampling rate per component of 6144 Hz. One complete measurement actually consisted of 512 individual samples, spanning a time interval of 83.3 ms, of the three vector components of the magnetic field. During later analysis, the data resulting from each measurement were Fourier transformed [Mathews and Walker, 1965] to obtain the strengths of the field components with frequencies falling in each of 255 frequency bins, the first extending from 0 to 6 Hz, the second from 6 to 18 Hz, the third from 18 to 30 Hz, and so on up to the 255th bin extending from 3054 to 3066 Hz. A "spot" Multiwave II measurement consisted of a sequence of four measurements, each separated from the next by 10 s.

The Multiwave II unit was calibrated daily by using a Helmholtz system that produced square wave magnetic fields (fundamental frequency of 60 Hz) with nominal resultant field strengths of 2.5 and 50.0 μT. The magnetic field measurements made with the Multiwave II unit were accurate to better than $\pm 5\%$.

We used a second meter (Model HI-3603, Holaday Instruments, Eden Prairie, MN) with a frequency bandwidth extending from 8 to 300 kHz to directly measure the rms x, y, and z components of the VLF magnetic fields produced by TV sets. The estimated accuracy of this meter, as specified by the manufacturer, was $\pm 10\%$.

Spot ELF and VLF measurements were obtained at horizontal distances of 50, 100, 175 and 250 cm from the screens of *operating* TV sets used for viewing programs. All these measurements were at a height of 60 cm above the floor. Additional ELF measurements were taken 50 cm from the screens at elevations of 30 and 90 cm. To minimize the time required to collect the magnetic field data needed to characterize TV sets, background ELF and VLF measurements with the TV set turned off were only taken 100 and 250 cm from sets (elevation = 60 cm). Because we expected subjects would sit closer to operating TV sets used for video games, measurements were taken at horizontal distances of 25, 50, 100, and 200 cm (elevation = 60 cm). Additional ELF measurements were taken at 50 cm with elevations of 30 and 90 cm. Background measurements were taken at 25 and 200 cm (elevation = 60 cm).

Aggregation of Frequency Spectra

Every Multiwave II spot measurement yielded a frequency spectrum (i.e., a table or graph of magnetic field strength vs. frequency) of the *x*, *y*, *z*, and resultant field components for each of four serial measurements. We expected that, while the magnitudes of the magnetic fields produced by different TV sets would vary, their frequency spectra would all be similar to the spectra of an ideal saw-tooth waveform. To evaluate the overall shape of the frequency spectra produced by TV sets, we thus divided, for each TV set, the field strength measured in each frequency bin by the strength of the 60 Hz component. We then aggregated the normalized spectra from different TV sets by computing the mean across TV sets of each frequency component.

Summarization of Data and Hypothesis Testing

The frequency distribution of magnetic field data taken in most environments is usually much closer to being log normal than normal [Kaune et al., 1987; Zaffanella, 1993]. This is also true for the magnetic field data reported in this paper. Consequently, magnetic field data were summarized by using geometric statistics. However, a careful scrutiny usually showed that the actual distributions of magnetic field data departed from exact log normality. Consequently, all of the analyses testing hypotheses reported in this paper were made by using nonparametric methods. The Wilcoxon signed-ranks test [Sokal and Rohlf, 1995] was used to test for differences between *matched* magnetic field data measured with televisions turned on and then off. The Kruskal–Wallis test [Sokal and Rohlf, 1995] was used to perform tests of differences in unmatched data stratified by a non-ordered group variable (e.g., comparison of magnetic fields produced by TV sets used to watch programs and TV sets used for game playing). Where independent variables were ordered quantities (e.g., size of TV picture tube or age of TV set), a nonparametric trend test [Cuzick, 1985] was used.

Separation of Television and Background Magnetic Fields

Because there are multiple sources of magnetic fields present in typical residences, the magnetic fields produced by an individual source, such as a TV set, can seldom be studied in isolation. Most residential magnetic fields in the extremely low frequency (ELF) range are produced by nearby electric power lines, ground currents, and home appliances [Zaffanella, 1993]. The frequency structure of these fields usually contains a strong 60 Hz component and odd-harmonic components (i.e., 180 Hz, 300 Hz, 420 Hz, ...) whose strengths grow progressively weaker with increasing frequency. For most residential sources, it appears that the strengths of the even-harmonic components are markedly smaller than those of nearby odd-harmonic components [Zaffanella, 1989; also see the ambient data presented later in this paper]. TV sets, on the other hand, produce substantial even-harmonic components, the strongest being at 120 Hz (Eq. (1)). Thus, the "cleanest" samples we obtained of the magnetic fields produced by TV sets were the 120 Hz field components. We thus used these components to separate the magnetic fields produced by ambient sources from those produced by TV sets.

Let T_{120} and A_{120} be the magnitudes of the 120 Hz magnetic fields produced, respectively, by a TV set under study and by other ambient sources. A_{120} was directly measured when the TV set was turned off and B_{120}, the magnitude of the vector sum of T_{120} and A_{120}, was measured when the TV was turned on. It is easy to show that T_{120} must lie in the interval $[|B_{120} - A_{120}|, B_{120} + A_{120}]$. The midpoint and half-width of this interval are, therefore, estimates of T_{120} and its associated uncertainty, ε_T. Taking into account that B_{120} can be smaller than A_{120},

$$\begin{aligned} T_{120} &= \max(B_{120}, A_{120}) \\ \varepsilon_T &= \min(B_{120}, A_{-120}). \end{aligned} \tag{2}$$

Background fields were only measured at distances of 100 and 250 cm from TV sets used for viewing program materials and at 25 and 200 cm from television sets used to play video games. Background fields at other points were estimated as a distance-weighted average of the measured data. (Since the average difference between the values of A_{120} measured at the two distances from TV sets was about 25%, and the ambient 120 Hz field was only, on average, 1–5% of the 120 Hz field measured closest to a TV when it was turned on, the inclusion of additional background measurements at distances other than 100 and 250 cm would not have substantially improved the accuracy of the estimates obtained from Eq. (2).)

At distances from a TV set considerably larger than the dimensions of the coils used to generate the vertical and horizontal deflection magnetic fields, the magnitude of the magnetic field, T, produced by either of them can be accurately approximated by the formula $T = \alpha/r^3$ [Reitz and Milford, 1960], where α is a constant and r is distance from the source. This equation is equally applicable to the resultant broadband magnetic field and to each of the frequency components of the field. Since we measured distance, R, from the screen of each set's picture tube, $r = R + R_0$ where R_0 is the distance inside the set to the deflection coils. Thus, the relation between R and the magnitude of the 120 Hz component of the resultant magnetic field produced by a TV set can be written as:

$$T_{120}(R) = \frac{\alpha_{120}}{(R + R_0)^3}. \tag{3}$$

Using Eq. (3), we calculated values for $T_{120}(R)$ at a height above the floor of 60 cm and at the distances from TV sets where field measurements were made. We then formed the weighted least squares sum

$$S = \sum_R \left[\frac{1}{\varepsilon_T^2}\right]\left[T_{120}(R) - \frac{\alpha_{120}}{(R + R_0)^3}\right]^2. \tag{4}$$

By placing the factor $1/\varepsilon_T^2$ in this sum, we weighted more heavily those measurements that had the least uncertainty introduced when background fields were subtracted. The values of α_{120} and R_0 were adjusted to minimize S. Then, we used Eq. (1), and Eq. (3) to write

$$T_{ELF}(R) = \pi\sqrt{\frac{2}{3}}\,\frac{\alpha_{120}}{(R + R_0)^3}. \tag{5}$$

The Holaday meter used to measure the VLF magnetic fields produced by TV sets provided only the rms field strength across its bandwidth. While the background magnetic field was quite small at these frequencies, the VLF signal from television sets was also small, which made the background subtraction a more significant problem than when working with the 120 Hz field components. We used the following procedure for the analysis of the VLF data: Electromagnetic theory tells us that the VLF field produced by a TV set can also be written in the form shown in Eq. (3) (with T_{120} and α_{120} replaced with T_{VLF} and α_{VLF}). The horizontal deflection coils that produce the VLF fields in front of a TV set are located close to the vertical deflection coils, so R_0 should have about the same value for both the ELF and VLF fields. Thus, since the background subtraction was much less of a problem for the 120 Hz ELF analysis described above, we used the value of R_0 yielded by this analysis for the VLF data. Then, because the background subtraction was least significant when $R = 50$ cm (or 25 cm for TV sets used for video games), we estimated α_{VLF} as follows:

$$\alpha_{VLF} = \begin{cases} T_{VLF}(R = 50\,\text{cm}) \times (50\,\text{cm} + R_0)^3 \\ \quad \text{for TV sets used for viewing programs} \\ T_{VLF}(R = 25\,\text{cm}) \times (25\,\text{cm} + R_0)^3 \\ \quad \text{for TV sets for playing video games} \end{cases} \tag{6}$$

where $T_{VLF}(R = 50\,\text{cm})$ and $T_{VLF}(R = 25\,\text{cm})$ are measured field strengths.

Estimating Children's Exposure Levels to the Magnetic Fields Produced by TV Sets

Equation (5) and its VLF analogue, the fitted values for α_{120}, α_{VLF}, and R_0, and questionnaire data on the locations where children sat while using their TV sets were used to calculate rms ELF and VLF magnetic fields produced by television sets at the locations children sat while watching them or playing video games with them.

RESULTS

Sampling Statistics

Magnetic field measurements were made on 72 TV sets that were used by children to watch TV programs. The mean estimated age of these TV sets was 5.0 y with a standard deviation of 1.3 y (range 1–7 y). Questionnaire data were obtained for 120 children in relation to their use of these TV sets. The mean number of children per home who supplied questionnaire data on their usage of a particular TV set was 1.67 (SD = 0.90). No questionnaire data were collected for two TV sets whose magnetic fields were measured during the pilot phase of the project. Thirty-two TV sets were each watched by one child who participated in the study, 30 sets were each watched by two participating children, six sets by three children, one set by four children, and one set by six children.

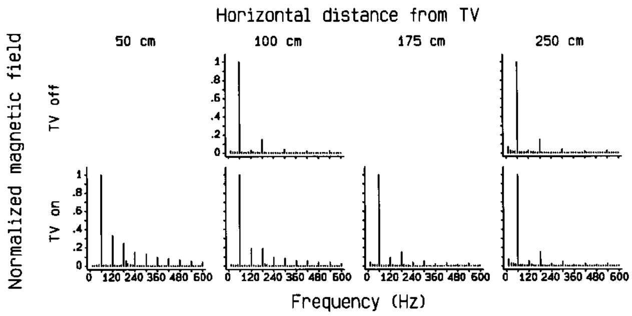

Fig. 1. Graphs showing aggregated normalized ELF magnetic field frequency spectra measured at distances of 50, 100, 175, and 250 cm from television sets used for viewing programs. TV sets were turned off when the spectra in the upper row were taken.

A total of 34 TV set/video game systems were measured. The mean age of the video game hardware at the time it was measured was 6.2 y (SD = 0.8 y, range 5–8 y). On the average, 1.1 questionnaire per home (SD = 0.5) were collected for each measured system. No questionnaire data were collected for two video game systems. Twenty-nine systems were each used by one child who participated in the study, two systems were each used by two children, and one system by three children.

Magnetic Field Frequency Spectra

Figure 1 shows aggregated normalized magnetic field spectra measured with TV sets used for viewing programs turned off (upper row) and on (lower row) at a height of 60 cm above the floor and various horizontal distances from their screens. Spectra for video games connected to TV sets were similar in appearance (data not shown). The aggregated spectra measured when TV sets were turned off exhibit similar spectral patterns: The magnitude of the 180 Hz component (3rd harmonic) was about 15% of the magnitude of the 60 Hz (fundamental) component while the 120 Hz component (second harmonic) was only 3% of the fundamental. The prevalence of odd harmonics in these spectra confirms our earlier statement that normal background fields consist largely of the fundamental and odd harmonics of 60 Hz.

The lower rows of spectra in Figure 1 show normalized data measured, respectively, with TV sets turned on. The pattern was similar for video games (data not shown). Note the presence of 2nd harmonic (120 Hz), 4th harmonic (240 Hz), and higher even harmonic magnetic fields, which are particularly evident close to the TV sets. For example, at 50 cm horizontally from operating TV sets (and 60 cm above floor level), the magnitudes of the 120 Hz and 180 Hz field components were 33% and 25% of the 60 Hz component.

Measured ELF Magnetic Fields

Table 1 lists geometric means summarizing static and ac magnetic fields measured near television sets with these sets either turned off or on. The first column of means in the table, labeled 0–6 Hz, summarizes the static fields. The values in this column are much larger than the other values in the table because this component of the magnetic field includes the geomagnetic field produced by the earth. We found no statistically significant differences between static field levels measured at 100 and 250 cm with television sets switched on or off, indicating that these appliances were not a measurable source of static magnetic fields.

The second column of geometric means in Table 1 lists the rms magnetic field measured across the entire broadband (6–3066 Hz) ELF bandwidth

TABLE 1. Geometric Means Summarizing ELF and VLF Magnetic Fields Measured Near 72 TV Sets Used for Viewing TV Programs

			Geometric mean magnetic field (μT)						
TV status	Distance from TV (cm)	Height above floor (cm)	0–6 Hz	6–3066 Hz	6–54 Hz	54–606 Hz	606–3066 Hz	120 Hz	8–200 kHz
on	50	30	52.2	0.215	0.0020	0.214	0.0100	0.0450	
on	50	60	51.8	0.256	0.0023	0.255	0.0139	0.0655	0.0303
on	50	90	51.4	0.277	0.0023	0.275	0.0162	0.0785	
off	100	60	51.8	0.102	0.0015	0.102	0.0030	0.0019	0.0026
on	100	60	51.9	0.138[a]	0.0017	0.138[a]	0.0051[a]	0.0186[a]	0.0106[a]
on	175	60	51.6	0.107	0.0016	0.106	0.0033	0.0057	0.0055
off	250	60	52.0	0.100	0.0021	0.098	0.0030	0.0018	0.0027
on	250	60	52.0	0.103	0.0020	0.101	0.0031[b,c]	0.0032[a]	0.0045[a]

[a] $P < 10^{-4}$, Wilcoxon signed-rank test, comparison between TV-on and TV-off measurements at same distance.
[b] $P < 10^{-2}$, Wilcoxon signed-rank test, comparison between TV-on and TV-off measurements at same distance.
[c] 54 of 71 TV sets had larger TV-on than TV-off magnetic fields.

covered by the Multiwave II magnetic field measurement system. Total magnetic field strengths measured 50 cm in front of the screens of television sets were substantially larger than fields measured at greater distances. Since no TV-off measurements were made at this distance, we could not directly determine whether field levels were elevated when TV sets were turned on. However, since field levels were elevated at a distance of 100 cm, where both TV-on and TV-off measurements were made (rows 4 and 5, Table 1), it is clear that geometric mean ac magnetic field levels were elevated at 50 cm when TV sets were turned on. At a distance of 250 cm, the geometric mean ac fields measured with TV sets turned on and off were not statistically significantly different.

The next three columns in Table 1 present the Multiwave II ac magnetic field data subdivided into three frequency ranges, the sub-power-frequency range (6–54 Hz), the power-frequency range (54–606 Hz), and the supra-power-frequency range (606–3066 Hz). At distances of 100 and 250 cm from the TV sets, there were no statistically significant differences between the TV-on and TV-off sub-power-frequency magnetic fields. The power-frequency component was significantly elevated at 100 cm, but not at 250 cm. The supra-power-frequency fields were significantly elevated at both distances (100 and 250 cm) when TV sets were turned on. (The reader may wonder about the 250 cm result since the geometric mean magnetic fields listed in Table 1 differ by only 3%. However, the Wilcoxon signed-rank test yields a P-value of .0021 and, because 54 of 71 sets had larger TV-on than TV-off supra-power-frequency fields, a simple sign test yields a P-value of 10^{-5}.)

The next column presents geometric mean 120 Hz magnetic field levels measured at various distances from TV sets. Note the striking increase in 120 Hz field levels when TV sets were turned on. For example, at 100 cm horizontally in front of TV sets and 60 cm above floor level, geometric mean magnetic field levels increased about 10 times over ambient levels when TVs were turned on. This observation illustrates why we concentrated on the 120 Hz component to separate the magnetic fields produced by TV sets from the fields produced by other ambient sources.

The final column in Table 1 summarizes the VLF magnetic field measurements near TV sets used for viewing programs. At 100 cm from sets, the geometric mean VLF magnetic field was 0.0106 μT when TV sets were on and was 0.0026 μT when sets were turned off. This difference was statistically significant, as was the difference in field strengths measured 250 cm from TV sets.

Table 2 presents comparable data to those in Table 1 for TV sets that were used by children to play video games. Turning on and playing a TV/video game system did not significantly increase static (0–6 Hz) magnetic field levels at distances of 25 and 200 cm from the units. However, at 25 cm, all time-varying field components were significantly increased when the systems under test were turned on. At a distance of 200 cm, only the supra-power-frequency, 120 Hz, and VLF field components were significantly increased by playing video games.

ELF Magnetic Fields Produced by Television Sets

This section presents the results of the fitting process, described earlier in Materials and Methods, that was used to affect a separation of the magnetic fields produced by television sets from fields produced

TABLE 2. Geometric Means Summarizing ELF and VLF Magnetic Fields Measured Near 34 TV Sets Used for Playing Video Games

TV status	Distance from TV (cm)	Height above floor (cm)	Geometric mean magnetic field (μT) 0–6 Hz	6–3066 Hz	6–54 Hz	54–606 Hz	606–3066 Hz	120 Hz	8–200 kHz
off	25	60	52.2	0.108	0.0013	0.108	0.0029	0.0020	0.0034
on	25	60	52.0	0.515[a]	0.0059[a]	0.513[a]	0.0355[a]	0.1843[a]	0.0823[a]
on	50	30	52.9	0.191	0.0021	0.190	0.0103	0.0506	
on	50	60	52.3	0.238	0.0027	0.237	0.0147	0.0741	0.0322
on	50	90	52.3	0.264	0.0029	0.264	0.0166	0.0845	
on	100	60	53.0	0.116	0.0015	0.116	0.0050	0.0208	0.0104
off	200	60	52.8	0.078	0.0017	0.077	0.0028	0.0016	0.0031
on	200	60	53.0	0.086	0.0014	0.086	0.0029[b,d]	0.0046[a]	0.0043[c]

[a]$P < 10^{-4}$, Wilcoxon signed-rank test, comparison between TV-on and TV-off measurements at same distance.
[b]$P < 10^{-2}$, Wilcoxon signed-rank test, comparison between TV-on and TV-off measurements at same distance.
[c]$P < 0.05$, Wilcoxon signed-rank test, comparison between TV-on and TV-off measurements at same distance.
[d]26 of 34 TV sets had larger TV-on than TV-off magnetic fields.

by other ambient sources. As described there, the magnetic fields produced by TV sets were fitted to a theoretical form. With a few exceptions, the agreement between calculated and measured data for each TV set was very good. As a measure of "goodness of fit", the residual difference between fitted and measured values was calculated for each distance, and the "error" for each TV set was defined as the standard deviation of the residuals for that TV set. Except for three TV sets, one used to watch programs and two used to play video games, all fitting errors were <0.005 μT. Further examination of the data for these three sets indicated that the fit for the one set used for viewing programs was invalid because the ambient 120 Hz magnetic field in this particular home was sufficiently large (≈ 0.012 μT) to overwhelm the magnetic field from the TV set at distances in front of its screen of 100 cm and larger. On the other hand, the data for the two TV sets used for playing video games that had fitting errors of >0.005 μT exhibited no behavior that, in our judgment, justified their exclusion, so they were included in all of the results presented in this and later sections.

Table 3 presents geometric statistics summarizing broadband ELF magnetic fields at distances of 25, 50, 100, 200, and 300 cm produced by TV sets used for viewing programs and for playing video games. Note that at 50 cm from TV sets, the geometric mean magnetic fields were about 0.17–0.19 μT, dropping rapidly as distance from the set increased, so that at 300 cm from sets, the geometric mean rms field was only 0.004 μT. There were no statistically significant differences between the magnetic fields calculated at each distance for TV sets used for viewing programs and TV sets used for playing video games ($.20 \leq P \leq .65$, Kruskal–Wallis test).

The broadband ELF magnetic fields produced by TV sets were evaluated according to brand, picture-tube size, or age. The 71 TV sets used for viewing programs included in this data set were sold under 23 brand names. Using the magnetic field produced 50 cm from each set as the dependent variable, there was no substantial evidence that broadband ELF magnetic field levels varied among brands ($P = .15$, Kruskal–Wallis test). The average age of the TV sets at the time of our measurements was 5.0 y (SD = 1.3 y). We found no evidence that magnetic fields varied by age ($P = .61$, nonparametric trend test), although the statistical power to test this hypothesis was limited because of the small dispersion in the ages of the TV sets included in the study. In contrast, we did find that TV screen size (measured along the diagonal) was a significant determinant of the strength of the magnetic fields produced by TV sets ($P = 10^{-5}$, nonparametric trend test). TV sets with larger screens produced, on average, larger magnetic fields at 50 cm from the units.

VLF Magnetic Fields Produced by Television Sets

The broadband VLF TV magnetic field data were analyzed as described earlier. The agreement between measured and calculated fields was not as good as that found for the 120 Hz field components because of the presence of larger background fields. Thus, the data in Table 4 summarizing the broadband VLF magnetic fields produced by TV sets are less reliable than the ELF data presented in Table 3. There were no statistically significant differences between the VLF magnetic fields calculated at each distance for TV sets used for viewing programs and TV sets used for playing video games ($.33 \leq P \leq .98$, Kruskal–Wallis test).

The VLF magnetic field levels at 50 cm from each of the TV sets used for viewing program materials did not differ significantly among brand names ($P = .46$, Kruskal–Wallis test) or TV-set age ($P = .41$, nonparametric trend test). As was the case for the ELF data, broadband VLF magnetic fields measured at 50 cm increased with increasing picture tube size ($P = .0062$, nonparametric trend test).

TABLE 3. Broadband ELF Magnetic Fields Produced at Standard Distances From TV Sets Used for Viewing Programs and Playing Video Games

	TV sets used to view programs			TV sets used to play video games		
Distance from TV set (cm)	N[a]	Geometric mean (μT)	Geometric SD	N	Geometric mean (μT)	Geometric SD
25	71	0.419	2.04	34	0.473	1.68
50	71	0.170	1.74	34	0.189	1.51
100	71	0.049	1.54	34	0.054	1.45
200	71	0.011	1.46	34	0.011	1.47
300	71	0.004	1.46	34	0.004	1.51

[a]Data for one TV set included in Table 1 were dropped because it was not possible to accurately remove the background ambient magnetic field.

TABLE 4. Broadband VLF Magnetic Fields Produced at Standard Distances From TV Sets Used for Viewing Programs and Playing Video Games

	TV sets used to view programs			TV sets used to play video games		
Distance from TV set (cm)	N[a]	Geometric mean (μT)	Geometric SD	N	Geometric mean (μT)	Geometric SD
25	71	0.0743	2.06	34	0.0823	2.26
50	71	0.0302	1.84	34	0.0329	2.04
100	71	0.0087	1.74	34	0.0093	1.90
200	71	0.0019	1.74	34	0.0020	1.85
300	71	0.0007	1.76	34	0.0007	1.84

[a]Data for one TV set included in Table 1 were dropped because it was not possible to accurately remove the background ambient magnetic field.

TABLE 5. Summary of Distances Between Children and TV Sets They Used for Viewing Programs or Playing Video Games.[a] Children and Mothers Were Separately Asked to Specify the Location of the Former During This Activity.

Child's activity	Person specifying distance	N	Mean (cm)	SD (cm)	Min (cm)	Max (cm)
Viewing programs	Child	120	231	95	74	540
Viewing programs	Mother	120	229	94	74	540
Playing games	Child	36	152	41	90	229
Playing games	Mother	36	149	42	68	229

[a]Data included for those children who watched TV sets whose magnetic fields could be isolated from other ambient sources.

Children's Exposures to Television Magnetic Fields

We now turn to the main goal of this paper: estimating the magnetic field from TV sets that children are actually exposed to while watching TV programs or playing video games connected to TVs. Table 5 summarizes the distances between children and TV sets. We found little difference between the distance assessments based on children's and mothers' questionnaire responses regarding the locations where the former sat while using TV sets, because 151 of 156 responses by mothers agreed with their children's identifications of locations where they sat while watching TV programs or while playing video games. Also apparent from Table 5 is the substantially closer distance of children to the TV sets used for playing video games compared to their distances to TV sets used to view programs ($P < .0001$, Kruskal–Wallis test).

Using the procedure described in Materials and Methods, we calculated exposure values for 120 children who watched 70 television sets and 36 children who played 32 video games. The number of TV sets and video games included in this calculation are less than the total number that were measured because we did not obtain questionnaire data for all. Note that in all previous analyses reported in this paper, the TV set (or TV set/video game) was the fundamental unit of analysis. However, in this section, the child is the unit of analysis, which means that some TV sets that were used by more than one child contributed multiply to the data in Table 6.

The distribution of broadband ELF and VLF exposure levels for children that watched TV and

TABLE 6. Geometric Statistics Summarizing Broadband ELF and VLF RMS Magnetic Fields Produced at Locations Where Children Normally Resided While Watching Television or Playing Video Games

	Watching television			Playing video game		
Frequency range	N	Geometric mean (μT)	Geometric SD	N	Geometric mean (μT)	Geometric SD
ELF	120	0.0091	3.01	36	0.0227	1.87
VLF	120	0.00157	3.23	36	0.00376	2.21

children who used TV sets to play video games were approximately log-normally distributed. Table 6 presents summary statistics for these exposure levels. The ELF and VLF exposure levels while watching TV programs was markedly more variable, but smaller on average by about a factor of 2, than the exposure levels while playing video games.

DISCUSSION AND CONCLUSIONS

The geometric mean magnitude of the background ELF (6–3066 Hz) magnetic field (i.e., the field measured with TV sets turned off) was about 0.08–0.1 μT in the homes of subjects enrolled in the study (Tables 1 and 2). These values are somewhat larger than typical values measured in the US. For example, Swanson and Kaune [1999] surveyed magnetic field data for US residences and concluded that the best estimate of the nation-wide geometric mean residential magnetic field was about 0.06–0.07 μT. Interestingly, in an earlier study that we performed in the same geographical area [Kaune et al., 1994], the geometric mean of the ambient magnetic fields measured in the living rooms (i.e., in the rooms most likely to contain TV sets) of 29 homes was about 0.1 μT, also somewhat elevated relative to the US estimates of Swanson and Kaune. Perhaps background ambient ELF magnetic fields in residences located in Washington DC and its Maryland suburbs may be larger than the US national average.

Questionnaire-based assessment of magnetic field exposures from TV sets might have substantial errors, because of variability which is not accounted for. The sources of variability include intrinsic characteristics of TV sets such as their brand, size, or age, and the distances between the subjects and their TV sets on the other. Using the data gathered in this study, we can evaluate the sizes of these sources of variability. First, consider intrinsic TV characteristics. The mean distance between subjects and TV sets used to watch programs was 230 cm (Table 5). Table 3 shows that at a fixed distance of 230 cm, the geometric standard deviation of the magnetic fields produced by 71 TV sets was about 1.5. By comparison, the geometric standard deviation of the ambient background magnetic fields measured in the study was about 2.8. That is, variability associated with TV characteristics was small compared to the natural variability in non-TV ambient magnetic fields in residences. This result suggests that it may *not* be necessary to obtain information about most of the characteristics of TV sets in a questionnaire-based TV exposure assessment.

To examine the exposure variability associated with distance, we used Eq. (5) to calculate the magnetic field at the locations of the 120 children enrolled in the study relative to a single ‘‘typical’’ TV set with R_0 and α_{ELF} set equal to average values for all the TV sets included in the study. The geometric standard deviation of the resulting exposure distribution was about 2.9, a value that is comparable to the variability in the ambient magnetic fields in residences. This result suggests that it is important to account for the distance between children and the TV sets they are watching when assessing their exposure to the magnetic fields produced by these sources.

The magnetic fields produced by TV set/video game systems could in principle have been different from those associated with the sets used for watching TV programs. However, as noted earlier, magnetic field levels measured at distances of 50 and 100 cm from the screens of TV sets were the same regardless of whether they were used to view programs or play games. This result suggests, but does not conclusively prove, that all magnetic fields produced by the game hardware needed to play video games were small in magnitude compared to the fields produced by TV sets. Yet, children's magnetic field exposure levels were larger, by about a factor of 2.3, when children used TV sets to play video games than when they watched TV programs. The major reason for this difference was because children sat about 75 cm closer, on average, to their TV sets while playing games than while watching TV programs (Table 5).

The geometric mean ELF magnetic field exposure levels for TVs used to watch programs (0.0091 μT) and play video games (0.0227 μT) were quite small compared to typical ambient levels in US homes. Geometric mean ambient levels measured in the homes in this study with TV sets switched off were approximately 0.1 μT, 11 times larger than the geometric mean ELF magnetic field exposure levels attributable to TV watching and about five times larger than geometric mean exposure levels attributable to video game playing. That is, children's overall ELF exposure levels were only very slightly affected by exposures from TV sets.

On the other hand, our findings show that the frequency spectra of the magnetic fields produced by TV sets were different in several respects from the spectra of typical ambient magnetic fields. In particular, the magnetic fields produced by TV sets included components at frequencies where ambient magnetic fields were usually very small. First, consider the second harmonic ELF magnetic field at 120 Hz. In the ambient magnetic field data acquired when TV sets were turned off, the geometric mean of the 120 Hz components is about 0.0018 μT, about 1.8% of the size of the overall geometric mean ELF magnetic field. If we assume this ratio is representative of the entire US, we may estimate that the geometric mean ambient 120 Hz magnetic field in this population is about 0.001 μT (i.e., 1.8% of the national value estimated by Swanson and Kaune [1999]). We may also estimate exposure levels for 120 Hz magnetic fields produced by TV sets. Equation (1) indicates that the ratio of the 120 Hz components to the broadband ELF components of the magnetic fields produced by TV sets will be 0.39. Applying this to the ELF exposure levels listed in the first row of Table 6, we estimate that exposure levels to the 120 Hz magnetic fields produced by TV sets will be about 0.004 μT when TV sets are being used to watch programs and about 0.009 μT when they are being used to play video games. Both of these values are significantly larger, by factors of about 3 and 7, than the ambient 120 Hz magnetic field we just estimated, indicating that TV sets will significantly elevate the total residential 120 Hz magnetic field exposure levels while they are turned on.

However, even though people's exposure levels to 120 Hz magnetic fields are increased in most homes when they watch television sets, the geometric mean size of these levels (0.004–0.009 μT) is still small relative to overall broadband ELF magnetic field levels in homes (about 0.065 μT). Thus, it seems unlikely that these fields could have any biological impact unless some part of the body has a substantially enhanced sensitivity to 120 Hz compared to other frequencies, especially 60 Hz. At this time, it would be highly speculative to assume that such a "resonance" exists.

Next, consider the frequency band extending from 606–3066 Hz. According to Tables 1 and 2, ambient background levels are about 0.003 μT. With the notation of Eq. (1), the rms magnetic field, T_{supra}, in this frequency range produced by TV sets is $T_{supra} = \sqrt{\sum_{n=11}^{51}(T_n)^2} = (T_{ELF}\sqrt{6}/\pi)\sqrt{\sum_{n=11}^{51}(1/n^2)}$. Carrying out this calculation by using values for T_{ELF} from Table 6, we estimate geometric mean exposure levels for children watching TV programs and playing video games of 0.002 and 0.005 μT, respectively. These values are comparable to, or larger than, the background levels in this frequency band. Again, these values are small relative to normal broadband ELF levels found in homes. However, magnetic fields also induce electric fields and currents inside conducting bodies, and the strength of these induced components is directly proportional to frequency. Consequently, induced current densities, J_{supra}, in the human body in the 606–3066 Hz frequency range can be written as $J_{supra} = \sqrt{\sum_{n=11}^{51}(\gamma_n n\omega_{60}T_n)^2}$, where γ_n is a function that depends on position within the body and tissue impedances and ω_{60} is the angular frequency of the 60 Hz fundamental. In the ELF range, it is reasonable to approximate γ_n as independent of frequency [Kaune and Gillis, 1981]. Thus, using Eq. (1) again,

$$J_{supra} \approx \gamma_{60}\omega_{60}(T_{ELF}\sqrt{6}/\pi)\sqrt{\sum_{n=11}^{51}1}$$
$$= \gamma_{60}\omega_{60}T_{ELF}\sqrt{246}/\pi.$$

Similarly, the current induced by a 60 Hz magnetic field with the same spatial structure would be $J_{60} = \gamma_{60}\omega_{60}T_{60}$. Thus, the 60 Hz magnetic field that would be required to induce in the body the same magnitude of current as the geometric mean 606–3066 Hz magnetic fields produced by actual TV sets used to watch programs or play video games, would be $T_{60} = T_{ELF}\sqrt{246}/\pi = 0.045\,\mu$T or 0.11 μT, respectively, values that are comparable in size to broadband ambient levels in US residences.

The geometric mean VLF background magnetic fields measured near TV sets when turned off was about 0.003 μT (Tables 1 and 2). On the other hand, the VLF magnetic field exposure levels we calculated for TV use were 0.0016 μT while watching programs and 0.0038 μT while playing games (Table 6). These values are large enough to conclude that TV watching and, to a greater extent, playing video games measurably elevated VLF magnetic field exposures to our study population relative to background levels. Taking into account the higher frequencies of these components, we calculate that the levels of the currents induced by VLF magnetic field exposures to children watching TV programs or playing video games are equivalent to those induced by a TV producing, respectively, a 0.4 μT or 1.0 μT ELF magnetic field. In other words, the currents induced in children by the VLF magnetic fields produced by TV sets will be much larger, by about a factor of 50, than the currents induced by the ELF components produced by these sources. Furthermore, one can show that VLF induced currents, including all frequency components in the bandwidth 8–200 kHz, will be similar in size to those induced by a 1 to 3 μT 60 Hz magnetic field. That is, induced VLF currents from TV sets will be much larger in size than those induced by background levels of 60 Hz magnetic fields.

The magnitude of the static component of the magnetic field measured near TV sets, whether they were turned off or on, was about 52 μT. Since the major source of this component of the total magnetic fields was the earth, it is interesting to compare our measured value with the nominal geomagnetic field for Washington DC and its Maryland suburbs. During the summer of 1997, this component was 54.0 μT [NGDC, 1990], about 4% larger than the measured values. Thus, it appears that, on average, static magnetic fields inside homes were slightly lower than values outside, which suggests that some of the materials from which homes in this area are constructed may provide a small amount of magnetic field shielding.

Based on questionnaire data, Hatch et al. [1998] reported associations between the use of TV sets for watching programs by children and increased risk of acute lymphoblastic leukemia in a large epidemiologic study (640 matched case–control pairs) conducted in nine midwestern and mid-Atlantic states. In this study, mothers reported distances between subjects and the TV sets they watched or used to play games as "<4 feet (<1.2 m)," "4–6 feet (1.2–1.8 m)," and "≥ 6 feet (≥ 1.8 m)". In an additional analysis, we examined magnetic field exposures for these same categories. The first three rows of data in Table 7 list the resulting geometric-mean ELF exposure levels, and the second three rows VLF exposure levels. For children watching TV programs, both ELF and VLF magnetic field exposures drop by more than a factor of 10 between the distance categories "<4" and "≥ 6 feet." In other words, if the underlying factor that explains the association between TV usage and childhood leukemia risk observed by Hatch et al. [1998] is the magnetic fields produced by these appliances, risks likely would be markedly stronger in the "<4 feet" than in the "≥ 6 feet" category. Yet, Hatch et al. found similar risks in these two categories for those children who watched television the most. That is, for TV usage of more than 6 h/day, children who sat <4 feet and children who sat ≥ 6 feet away from TV sets had relative risks of contracting leukemia of 4.39 (95% CI = 1.75–11.04) and 4.67 (95% CI = 1.64–13.36), respectively, both about equally elevated relative to the baseline level for children who sat ≥ 6 feet while watching TV less than 2 h/day. The similarity of these risk estimates in distance strata with such widely varying exposure levels suggests that the magnetic fields emitted by TV sets are unlikely to explain the significantly elevated leukemia risks observed by Hatch et al. [1998].

However, it is also conceivable that these results indicate the presence of a dose–response curve where, once magnetic field exposure exceeds some threshold level, its magnitude is no longer important. If so, because the overall ELF TV exposure levels we calculated were small relative to ambient levels, it is tempting to suggest that the biologically important aspect of TV exposure may be its 120 Hz component, its 606–3066 Hz component, or its VLF component, all of which fall at frequencies where ambient levels are relatively smaller. The first candidate, 120 Hz magnetic fields, does not seem very plausible because of its very small magnitude relative to overall ELF background levels, although some sort of resonance phenomena could conceivably explain enhanced sensitivity at this frequency. Even though still small with respect to background ELF levels, the second candidate is perhaps more plausible because currents induced in the bodies of children by the 606–3066 Hz magnetic fields produced by TV sets will be comparable in size to currents induced by background ELF fields. The final candidate is the VLF fields produced by TV sets. The magnitude of these fields are also small (0.002 and 0.004 μT for TV sets used to view programs and play video games, respectively) but their ability to induce current and electric fields in the human body is greatly magnified because of their much higher frequency relative to ELF fields. Future investigations of the associations between disease and TV use and video game playing reported by Hatch et al. [1998] might, therefore, choose to concentrate on the VLF magnetic fields emitted by these sources.

Even though there are no substantial data suggesting that electric field exposure can affect human carcinogenesis [Portier and Wolfe, 1998], it is of course possible that epidemiologic results linking childhood leukemia with TV watching might be pointing to such an effect. The electric fields emitted

TABLE 7. Geometric Mean Broadband ELF and VLF Magnetic Field Exposure Levels Attributable to TV Watching by Children. Data are Stratified by Distance Between Subjects and TV Sets They Used.

Frequency range	Distance from TV	N	Geometric mean (μT)	Geometric SD
ELF	<4 feet (1.2 m)	16	0.056	1.79
ELF	4–6 feet (1.2–1.8 m)	28	0.020	1.52
ELF	>6 feet (1.8 m)	76	0.005	1.87
VLF	<4 feet	16	0.0102	1.93
VLF	4–6 feet	28	0.0034	1.80
VLF	>6 feet	76	0.0008	2.08

by VDTs have been studied by several groups. As noted earlier, Harvey [1983b] reported unperturbed (i.e., unaffected by the body of user) ELF and VLF electric field levels 30 cm from the screens of VDTs of 1.0–6.5 and 0.4–3.5 V/m, respectively. Sandström et al. [1993] reported that perturbed electric fields 50 cm in front of the screens of VDTs were too small to alter substantially the ambient levels in the offices they studied, which were in the range 10–100 V/m. It is not clear how to convert these data to unperturbed values. Evidently, the weight of available evidence suggests that ELF electric fields close to the screens of VDTs are comparable to or smaller than typical ambient levels. We are aware of only one report describing the electric fields produced by TV sets, and this report presents data for a single color TV set [Harvey, 1982]. This author reported that ELF and VLF electric fields measured 120 cm from a TV set were comparable in strength to the fields produced 30 cm from VDTs. Since most children sit at least this far from their TV sets (Table 5), it seems likely that their exposures to the ELF electric fields produced by these sources were comparable to or smaller than exposures to normal ambient levels.

We obtained no measurements of the levels of ambient VLF electric fields, but it seems very likely that the levels produced by TV sets (0.4–3.5 V/m [Harvey, 1983b]) are larger and are certainly capable of inducing larger currents in the body than the ELF electric fields produced by these sources. Thus, similar to our conclusion regarding magnetic fields, it seems appropriate to recommend that future studies consider including assessment of VLF electric fields from TV sets.

Finally, we note that our main results assume that children provided accurate responses regarding where they sat while watching TV or playing video games. Since we directly asked children about their current, rather than their historical, behavior in this regard and since we measured the distances between TV sets and the locations specified by the subjects, we have no reason to think that our distance data are not accurate.

In summary, this large comprehensive measurement study indicates that children's exposures to the magnetic fields produced by TV sets in the ELF range are small compared to normal ambient levels from other sources. The results of our quantitative study substantially reduce the likelihood that associations between TV use and childhood leukemia observed in epidemiologic studies are due to the magnetic fields produced by these appliances, although one may speculate that these associations could be indicative of a relation between leukemia and exposure to 120 Hz, 606–3066 Hz, and/or VLF electric or magnetic fields. Of these, VLF fields may be the most plausible candidate because currents induced in the body by these fields are markedly larger than those induced by the ELF fields produced by TV sets and by normal residential background magnetic fields.

Since the results reported in this study were obtained using a volunteer sample of families living in the Washington DC and its Maryland suburban areas, the findings require confirmation in other populations.

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REFERENCES

Chartier VL, Bracken TD, Capon AS. 1985. BPA study of occupational exposure to 60 Hz electric fields. IEEE Transactions on Power Apparatus and Systems PAS-104:733–744.

CRC. 1978. CRC standard mathematical tables. West Palm Beach, Florida: CRC Press.

Cuzick J. 1985. A Wilcoxon-type test for trend. Statistics in Medicine 4:87–90.

Deno DW, Silva JM. 1984. Method for evaluating human exposure to 60 Hz electric fields. IEEE Transactions on Power Apparatus and Systems PAS-103:1699–1706.

Gauger JR. 1985. Household appliance magnetic field survey. IEEE Transactions on Power Apparatus and Systems PAS-104:2436–2444.

Guy AW. 1987. Measurement and analysis of electromagnetic field emissions from 24 video display terminals in American telephone and telegraph offices in Washington, DC. Report to The National Institute of Occupational Safety and Health, Cincinnati, Ohio.

Harvey SM. 1982. Characteristics of low frequency electrostatic and electromagnetic fields produced by video display terminals. Report No. 82-528-K, Research Division, Ontario Hydro, Pickering, Ontario, Canada.

Harvey SM. 1983a. Characterization of low frequency magnetic fields produced by video display units. Report No. 83-504-K, Research Division, Ontario Hydro, Pickering, Ontario, Canada.

Harvey SM. 1983b. Analysis of operator exposure to electric fields from video display units. Report 83-503-K, Research Division, Pickering, Ontario, Canada.

Harvey SM. 1984. Electric-field exposure of persons using video display units. Bioelectromagnetics 5:1–12.

Hatch EE, Linet MS, Kleinerman RA, Tarone RE, Severson RK, Hartsock CT, Haines C, Kaune WT, Friedman D, Robison LL, Wacholder S. 1998. Association between childhood acute lymphoblastic leukemia and use of electrical appliances during pregnancy and childhood. Epidemiology 9:234–245.

IEEE. 1993. The new IEEE standard dictionary of electrical and electronics terms. The Institute of Electrical and Electronics Engineers, Inc., 345 East 47th Street, New York, NY 10017-2394.

Jokela K, Aaltonen J, Lukkarinen A. 1989. Measurements of electromagnetic emissions from video display terminals at the frequency range from 30 Hz to 1 MHz. Health Physics 57:79–88.

Kaune WT, Darby SD, Gardner SN, Hrubec Z, Iriye RN, Linet MS. 1994. Development of a protocol for assessing time-weighted-average exposures of young children to power-frequency magnetic fields. Bioelectromagnetics 15: 33–51.

Kaune WT, Gillis MF. 1981. General properties of the interaction between animals and ELF electric fields. Bioelectromagnetics 2:1–11.

Kaune WT, Stevens RG, Callahan NJ, Severson RK, Thomas DB. 1987. Residential magnetic and electric fields. Bioelectromagnetics 8:315–335.

Kavet R, Tell RA. 1991. VDTs: Field levels, epidemiology, and laboratory studies. Health Physics 61:47–57.

London SJ, Thomas DC, Bowman JD, Sobel E, Cheng T-C, Peters JM. 1991. Exposure to residential electric and magnetic fields and risk of childhood leukemia. American Journal of Epidemiology 9:923–937.

Marha K, Charron D. 1985. The distribution of a pulsed very low frequency electric field around video display terminals. Health Physics 49:517–521.

Mathews J, Walker RL. 1965. Mathematical methods of physics. New York: WA Benjamin, Inc.

NGDC. 1990. GEOMAG computer program, code E/GC1. National Geophysical Data Center, Boulder, Colorado.

Portier CJ, Wolfe MS. 1998. Assessment of health effects from exposure to power-line frequency electric and magnetic fields. NIH Publication 98-3981, National Institute of Environmental Health Sciences, Research Triangle Park, NC.

Preece AW, Kaune W, Grainger P, Preece S, Golding J. 1997. Magnetic fields from domestic appliances in the UK. Physics in Medicine and Biology 42:67–76.

Reitz JR, Milford FJ. 1960. Foundations of electromagnetic theory. Reading, MA: Addison-Wesley.

Sandström M, Mild KH, Stenberg B, Wall S. 1993. A survey of electric and magnetic fields among VDT operators in offices. IEEE Trans Electromagnetic Compatibility 35: 394–397

Sokal RR, Rohlf FJ. 1995. Biometry. New York: WH Freeman and Company.

Stuchly MA, Lecuyer DW, Mann RD. 1983. Extremely low frequency electromagnetic emissions from video display terminals and other devices. Health Physics 45:713–722.

Swanson J, Kaune WT. 1999. Comparison of residential power-frequency magnetic fields away from appliances in different countries. Bioelectromagnetics 20:244–254.

Tofani S, D'Amore G. 1991. Extremely-low-frequency and very-low-frequency magnetic fields emitted by video display units. Bioelectromagnetics 12:35–46.

Zaffanella LE. 1989. Pilot study of residential power frequency magnetic fields. EPRI EL-6509, Final Report, Electric Power Research Institute, Palo Alto, CA.

Zaffanella LE. 1993. Survey of residential magnetic field sources. Volume 1: Goals, results, and conclusions. Report TR-102759-V1, Electric Power Research Institute, Palo Alto, CA.